ECE 322L
Electronics 2

03/31/20 - Lecture 18

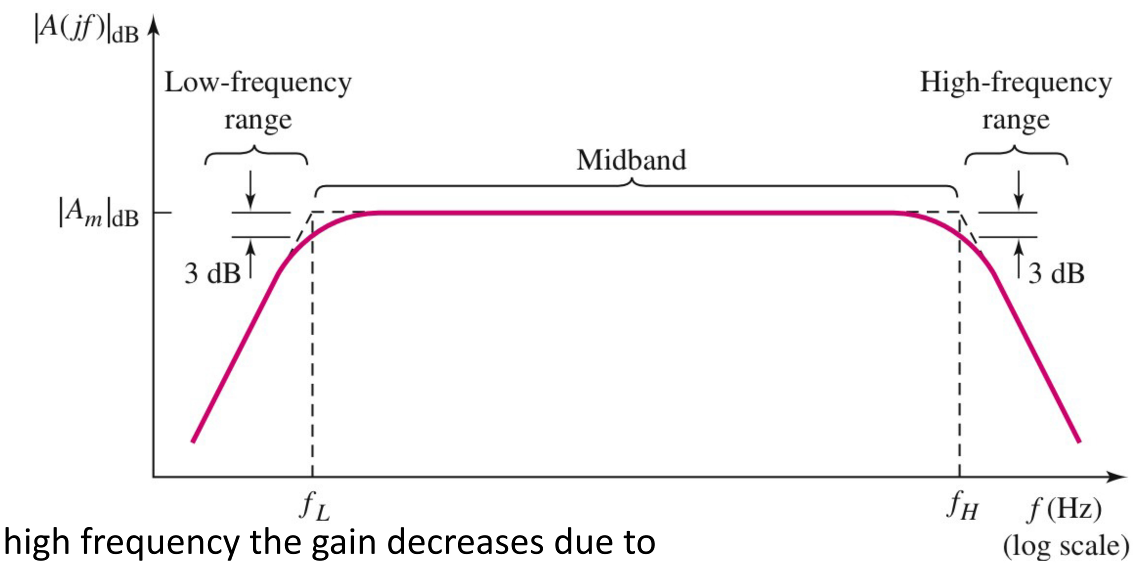
Capacitive effects in BJTs

Updates and overview

- Please, refer to the announcements on UNM Learn for the revised due dates.
- Midterm 2 will be next week. See the announcement on UNM Learn for additional details.

Today:

- High frequency response of BJT-based amplifiers
- Capacitance effects in a p-n junction
- Parasitic capacitance in a BJT
  (Neamen 7.4.1)
- Augmented π-model (Neamen 7.4.1)
- Miller effect (Neamen 7.4.4-7.4.5)

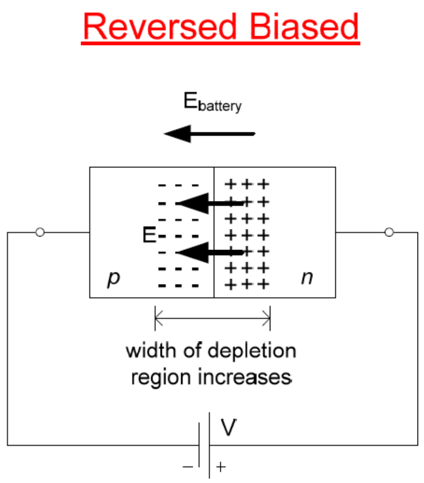


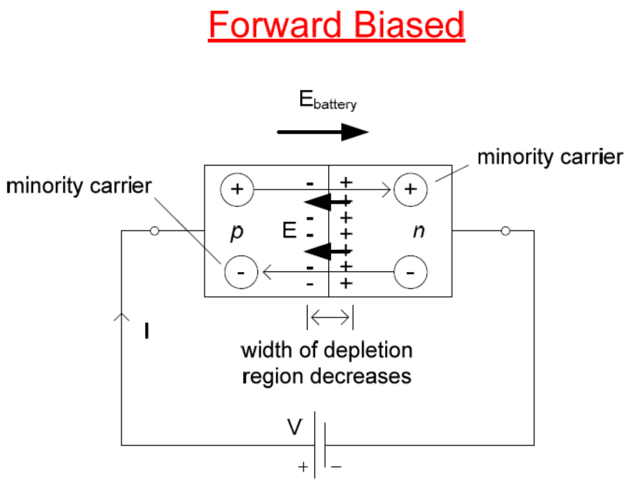
At high frequency the gain decreases due to

- Internal capacitances of the transistors
- Parasitic effects
- Load capacitors

This slides reminds you of the shape of the frequency response of the amplifier. In the previous lecture we modelled the effect of circuit capacitors at low and high frequency. In this and in the next lecture we'll focus on the internal capacitors of BJTs and FETs and how they affect the frequency response of an amplifier.

Capacitances of a pn junction





- Reverse biased junction:

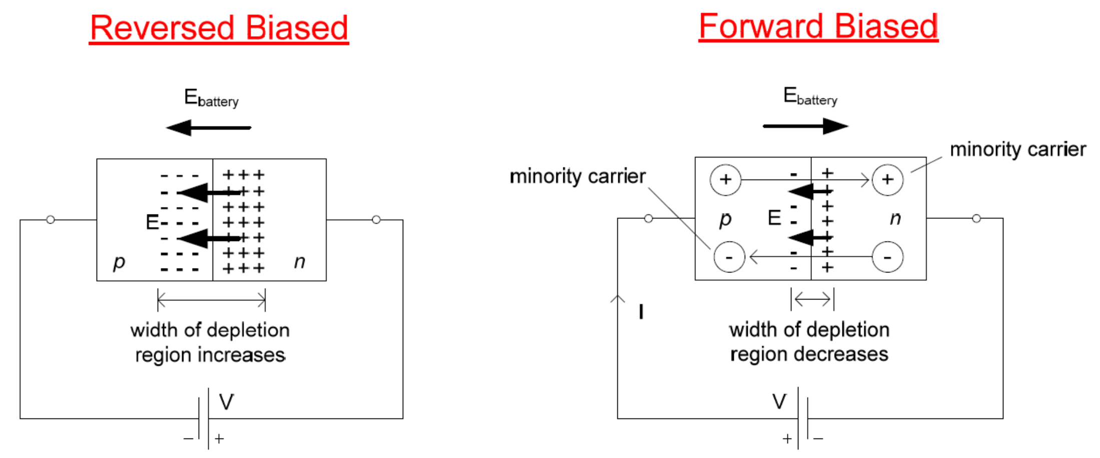
  Junction capacitance

- Forward biased junction:

  Junction capacitance and diffusion capacitance

As BJTs include 2 p-n junctions, it is important to review capacitive effects in a p-n junction in order to understand the origin of the BJT internal capacitors.

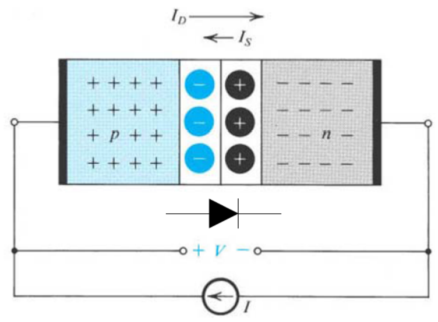
Junction capacitance of pn junction

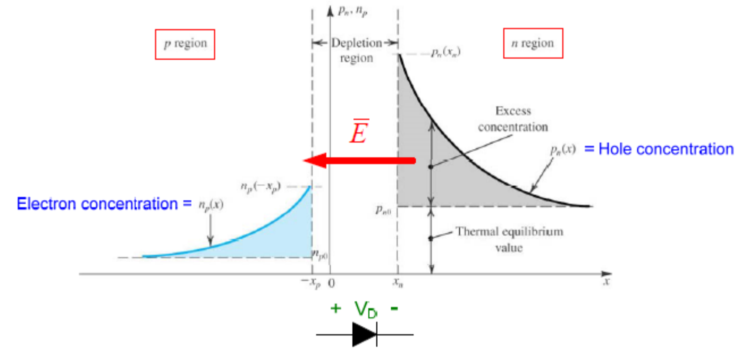


- The width of the depletion region (and the amount of fixed charge stored in it) will change depending on the applied voltage in both FB and RB junctions.
- These fixed charges create an electric field across the pn junction that will vary with time when a signal source is connected to the device.
- This overall effect can be modeled by what is called the junction capacitance

This slides explains the origin of a junction capacitance in a p-n junction.

Diffusion capacitance of a pn junction

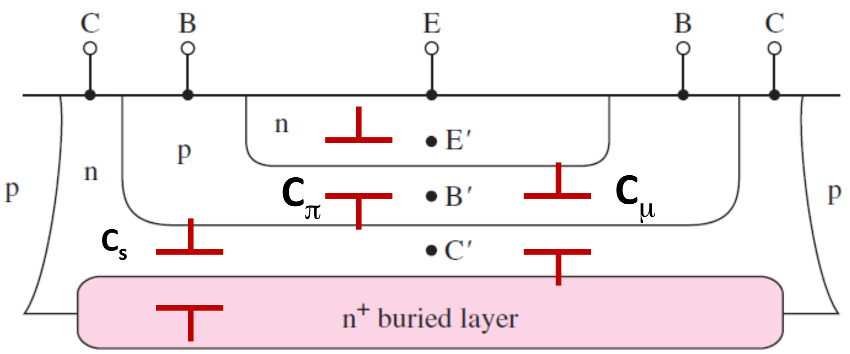




- In FB junctions holes are injected across the junction into the n region while electrons are injected across the junction into the p region.
- The concentration of these electrons and holes decreases away from the junction due to recombination effects.
- These concentration of charges create an electric field across the pn junction that will vary with time when a signal source is connected to the device.
- This overall effect can be modeled by what is called the charge storage capacitance or diffusion capacitance.

This slides explains the origin of a diffusion capacitance in a p-n junction.

Capacitances of in a BJT



Since the capacitor values are very small, their impedance at **low** and moderate frequencies is large.
I.E.:

$$Z_c = \frac{1}{j\omega C} \quad \text{is large if } \omega C \ll 1$$

In other words, at low and moderate frequencies, these capacitor impedances are approximately **open** circuits, and thus they can be **ignored**.

However, at **high** frequencies, the capacitor impedance can drop to **moderate** values (e.g., $K\Omega$s).

This schematic illustration identifies the three internal capacitors of a BJT.

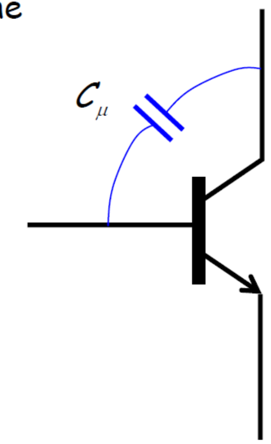
Capacitance associated with the B-C junction

$\underline{\underline{C_\mu}}$ *Junction capacitance*

C_μ is a parasitic capacitance between the **collector** and the **base**.

This capacitance is due to the *pn* **junction** (between collector and base).

Typical values of C_μ are a few picofarads or **less**.

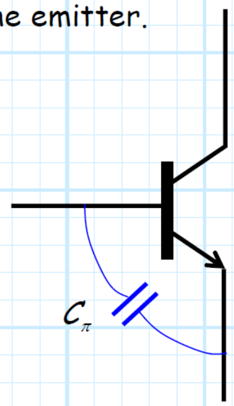


Valid in Forward-active region

This slide specify the nature of C_μυ ιν τηε φορωαρδ αχτιωε ρεγιον.

Capacitance associated with the E-B junction

C_π is a parasitic (i.e., small) capacitance between the base and the emitter.



This capacitance actually consists of **two** parts:

$$C_\pi = C_{je} + C_{de}$$

where:

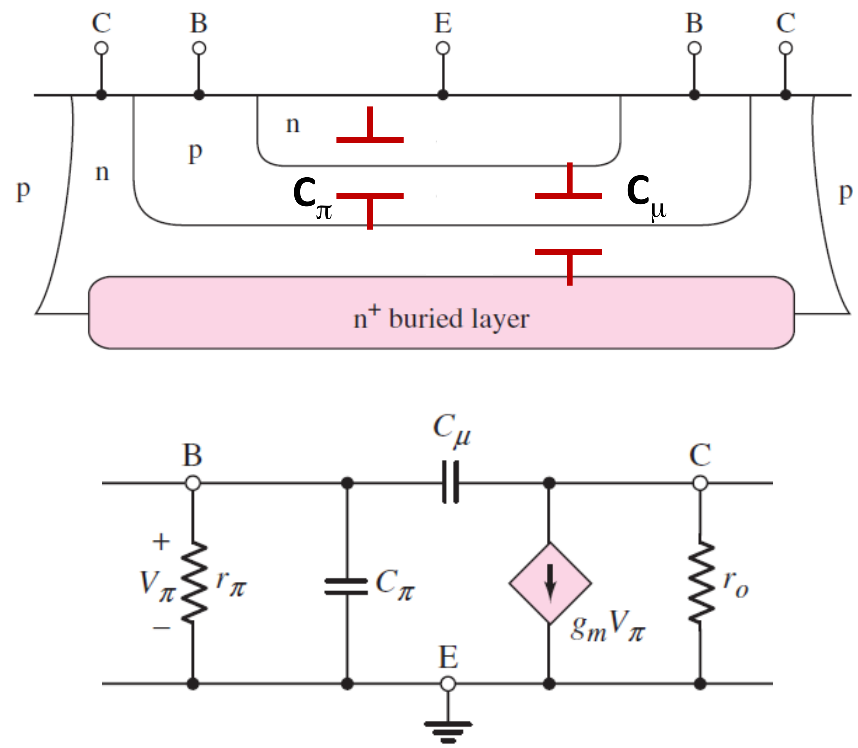
$$\left.\begin{aligned} C_{de} &= \text{diffusion capacitance} \\ C_{je} &= \text{junction capacitance} \end{aligned}\right\} \textit{pn} \text{ junction capacitance}$$

Typically, C_π is a **few picofarads**.

Valid in Forward-active region

This slide specify the nature of C_πι ανδ ιτσ ορδερ οφ μαγνιτυδε

Augmented π-equivalent circuit



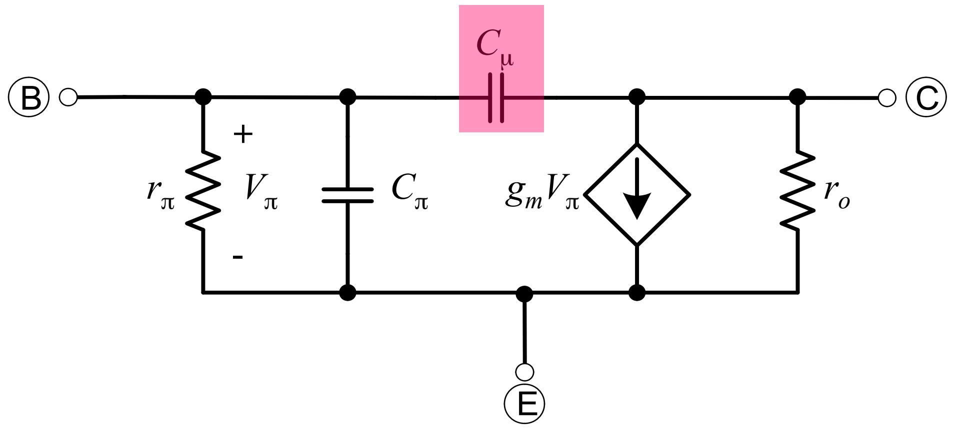
It is usually reasonable to neglect Cs as it is very small. This slides shows the augmented small signal model for BJT at high frequency

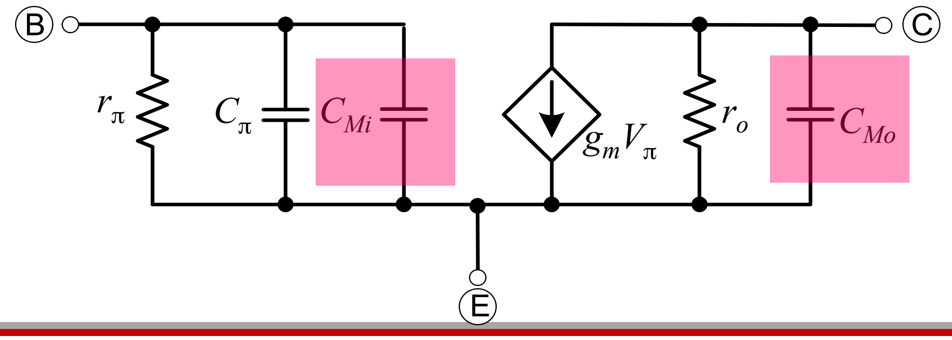
Miller's Theorem

- This theorem simplifies the analysis of amplifier at high frequency.
- The theorem states that if an impedance is connected between the input side and the output side of a voltage amplifier, this impedance can be replaced by two equivalent impedances, i.e. one connected across the input and the other connected across the output terminals.

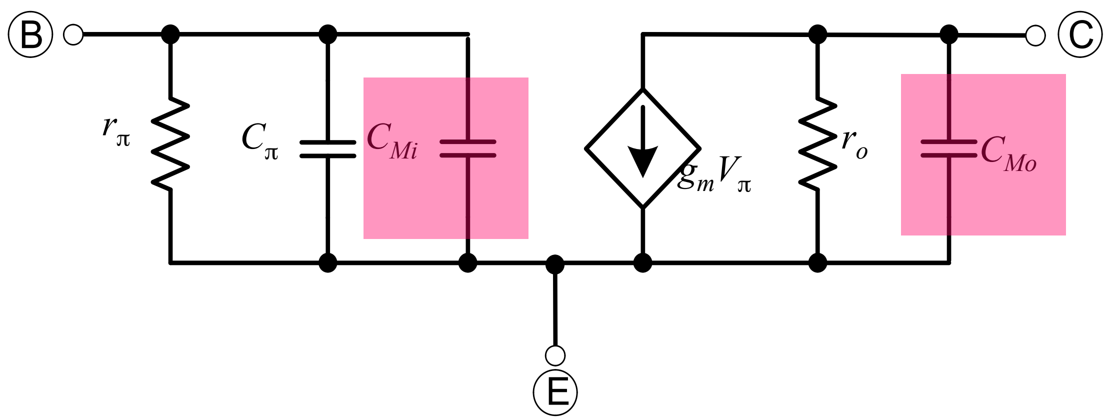
The Miller's theorem is relevant to determining the upper corned frequency and thus the bandwidth of an amplifier.

Miller's Theorem applied to a BJT





High-frequency hybrid-π model with Miller effect



$$C_{Mi} = C_\mu(1 - A_v) \; C_{Mo} = C_\mu\left(1 - \frac{1}{A_v}\right)$$ Miller approximation

G is the midband gain

Open-circuit time-constant method (OCTC)

Used to determine the high cut-off frequency for a circuit including n capacitors.

Step-by-step method

1.Draw the ac equivalent circuit including only the capacitors yielding a low pass response (All the other capacitors will act as short circuits).

2.Calculate the corner frequencies determined by each capacitor as $\omega_{Hi}=1/2\pi C_i R_{iH}$ by replacing all the other capacitors with open circuits.

Lecture 18-In class problem

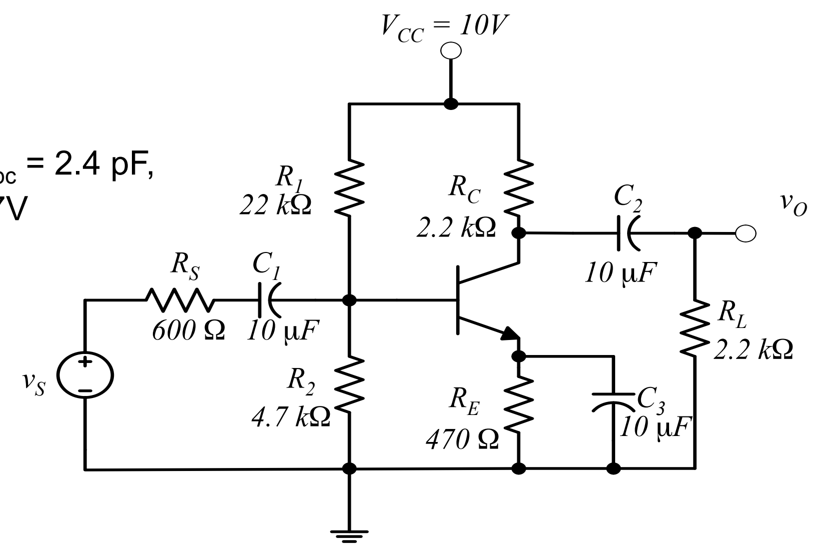
Given :

β= 125, C_{be} = 20 pF, C_{bc} = 2.4 pF,
V_A = 70V, $V_{BE}(on)$ = 0.7V

g_m=73.35 mA/V

r_o=36.8 kΩ

r_π=1.7 kΩ



Determine the upper cut-off frequencies for the circuits above